AFRL-IF-RS-TR-1999-206
Final Technical Report
September 1999

ENHANCEMENT OF TARGET DETECTION BY POLARIZATION TECHNIQUES

PAR Government Systems Corporation

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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1999	April 1998 - October 1998

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
ENHANCEMENT OF TARGET DETECTION BY POLARIZATION TECHNIQUES	C - F30602-98-C-0150 PE - 61102F PR - 2304 TA - ER WU - P1
6. AUTHOR(S) Michael Duggin	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) PAR Government Systems Corporation 314 South Jay Street Rome NY 13440	8. PERFORMING ORGANIZATION REPORT NUMBER PGSC # P11164-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory/IFEC 32 Brooks Road Rome NY 13441-4114	10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-IF-RS-TR-1999-206

11. SUPPLEMENTARY NOTES
AFRL Project Engineer: Jonathan C. Gregory/IFEC/(315) 330-4294

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for Public Release; Distribution Unlimited	

13. ABSTRACT *(Maximum 200 words)*

The objectives of this effort were to study the dependence of the degree of polarization of reflected light upon scene radiance level, and to study factors controlling the relationship between the polarization of recorded scene radiance and its intensity. A further objective was to extend upon previous work conducted for AFRL to better understand the enhancement of shadow through the use of polarization methods. While constrained by the wide spectral bands of the available sensor, the intent was to work towards finding whether there is a spectral dependence of polarization close to the red edge and blue edge, as well as the center of water absorption bands. This provides the potential to aid in discriminating camouflage nets and camouflaged vehicles, building, and structures from vegetation. Efforts demonstrated that scene radiance controls the degree of polarization in a given bandpass. It does not appear to matter whether the radiance level is controlled by shadow or by albedo; nor does it seem to matter (for the broad bandpasses used) the reflector. The reason to believe that polarization might provide additional information to narrow band reflected radiance (hyperspectral) information for vegetation/camouflage discrimination and for vegetation stress discrimination.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Polarization Scene Radiance Camouflaged Targets Spectralon Hue Saturation Multi-Hyperspectral Kodak DCS 460	28
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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1. INTRODUCTION

This scientific and technical report summarizes the work accomplished and information gained during the performance of AFRL contract #F30602-98-C-0150, Enhancement of Target Detection by Polarization Techniques. The objectives of this effort were to study the dependence of the degree of polarization of reflected light upon scene radiance level, and to study factors controlling the relationship between the polarization of recorded scene radiance and its intensity. A further objective was to extend upon previous work conducted for AFRL to better understand the enhancement of shadow through the use of polarization methods. While constrained by the wide spectral bands of the available sensor, the intent was to work towards finding whether there is a spectral dependence of polarization close to the red edge and to the blue edge, as well as at the centers of water absorption bands. This provides the potential to aid in discriminating camouflage nets and camouflaged vehicles, buildings, and structures from vegetation.

The technique for measuring polarization and for measuring reflectance involved some overlap with the Global Patriot '98 exercise. Both the measurement of polarization and the measurement of reflectance using a digital camera are novel and form the subject of draft research publications [Ref. 1, 2].

During 1987 and 1988, measurements were made on camouflage targets hidden in vegetation, camouflage nets located in vegetation, and camouflage nets co-located with calibration targets. The standard calibration targets consisted of panels of differing hue, as well as gray Lambertian standards. Measurements were also made of shadowed regions in order to determine to what extent shadow penetration may be aided by polarimetric methods.

Efforts demonstrated that scene radiance controls the degree of polarization in a given bandpass. It does not appear to matter whether the radiance level is controlled by shadow or by albedo; nor does it seem to matter (for the broad bandpasses used) the reflector. Previous work suggests that hue impacts the degree of polarization in reflected light. However there was no time to determine to what extent hue impacts the spectral distribution of the degree of polarization in reflected light. Nor was there time to analyze data obtained with differing view and illumination geometries.

There is reason to believe that polarization might provide additional information to narrow band reflected radiance (hyperspectral) information for vegetation/camouflage discrimination and for vegetation stress discrimination. Methods to explore this are discussed.

Recommendations are also made to analyze the remainder of the data collected to determine the band-dependence of the degree of polarization on scene radiance, and to determine the factors controlling the relationship between polarization characteristics and scene radiance levels. It is recommended that further investigation of the hue- and satuaration-dependence of polarization be performed to determine whether the degree of polarization depends on hue and saturation, as well as intensity. This, in turn, might be used to further discriminate man-made targets from vegetation and to distinguish camouflage from vegetation.

2. METHODS

Data was collected in 1997 and in 1998 with two different Kodak digital color infrared (CIR) cameras — Kodak DCS CIR 420 and 460. The CIR version was used to record polarization in the near infrared region. This camera is especially useful for vegetation detection and quantification. The DCS 460 CIR is based upon a Nikon N90 body, and it has a 3,072 x 2,048 pixel focal plane array. The DCS 420 CIR is similar to the DCS 460 but is one half the spatial resolution. Kodak manufactures the array for each camera. Each silicon array has a focal plane filter for each detector element. The array elements form a repeating motif consisting of a 2 x 2 kernel comprising two green filtered elements that are diametrically opposite— a red filtered element, and a blue filtered element. In its regular professional format, the camera has an on-the-focal plane infrared blocking interference filter whose -3 dB bandwidth is 400 nm - 700 nm. This prevents response in the near infrared region of the spectrum. The CIR camera used has an interference filter in front of the lens that has a -3dB bandwidth of 500 nm - 800 nm. With this, the blue filtered pixels cannot respond to blue light since the interference filter does not transmit in this spectral region. However, all of the array elements respond to the reflected infrared radiance passed in the 700 nm - 800 nm region. The green filtered pixels respond to green and to NIR radiance; the red filtered array elements respond to red plus NIR radiance; and the blue filtered pixels respond to NIR radiance only. By subtracting the response measured on the blue filtered pixel in a kernel in a proprietary weighted fashion from the green and the red filtered pixels in the array kernel, a green, a red, and an NIR response is obtained. A proprietary Kodak algorithm apportions red, green and blue radiance to each focal plane element, although in fact, each element records radiance in only one waveband. This is achieved by interpolating the nearest-neighbor and next-nearest-neighbor spatial distribution of radiance in each waveband. Cosmetically the effect is pleasing up to remarkable enlargements. However, it was discovered that images obtained over uniform targets of 2%, 50% and 100% spectral reflectance Spectralon appeared to have subtle colored patterns, and the spectral radiance frequency histograms were slightly broadened. This was an artifact of the Kodak spatial averaging algorithm.

It was found that the camera's meter had different near infrared and visible light sensitivities. Many tests were performed to ensure that the image was not saturated at radiance levels included in most scene elements. In order to record very low radiance levels, limited saturation was permitted over the 98% reflectance Spectralon standard. Tests showed a radiometric response linearity of 5% and 8-bit quantization. This is an order of magnitude better than can be achieved with film. The standard deviation of digital counts obtained from 56% and 100% Spectralon, illuminated by solar irradiance under clear sky conditions, was found to be 2% to 5% of the digital reading obtained by analyzing the digital images with ENVI, an image processing application [Ref. 3-5]. Typically sample sizes of Spectralon standard reflector images for statistical analysis were over 100,000 pixels. Regions of interest studied on MacBeth color checker gray scale elements and on other scene elements were generally greater than 400 pixels.

The linear polarizer was Polaroid HN38S film which was mounted in a holder that could be rotated on the front of the lens/interference filter assembly. Orientation of the polarizer was estimated to be within +/- 5 degrees. A sequence of exposures was made with the linear axis of the polarizer oriented at 0^0, 45^0, 90^0 and 135^0 relative to a reference direction (usually the vertical, except when nadir-view images of the standard reflector were obtained).

The image data was downloaded onto CD ROMs and subsequently transferred to Iomega Jazz cartridges and to a disk farm. The DCS 460 CIR stores images in a proprietary compressed TIFF format where each image in expanded form is 18.258 Mb.

Early results from the 1997 measurements were reported at the 1997 SPIE Conference in San Diego, CA, and at the 1998 ASPRS Conference in Tampa, FL [Ref. 3-7]. The use of a digital camera as an imaging polarimeter and as a field radiometer is discussed in draft research publications [Ref. 1, 2].

Discussions with Dr Walter Egan, a long-time researcher in the field of polarized light led to collaboration on a paper [Ref. 8]. This paper shows that the very sensitive measurements that were made in which radiance levels spanned the entire dynamic range of the digital camera and produced accuracies and precision an order of magnitude better than previously reported, were in accord with measurements Dr. Egan has made over several decades with non-imaging polarimeters, on totally disparate targets, ranging from lunar dust to agricultural crop canopies. This is interesting because it shows that the relationship between scene radiance and the degree of polarization does not depend on investigator, scene, or instrument.

3. RESULTS

An example of an image of a selection of reflectors is shown in Figure 1. This image is the average of the four images taken with the linear polarizer rotated at 45^0 relative orientations about the optic axis of the camera between exposures. The camera was mounted on a very rigid tripod to prevent camera movement between exposures. The HN38S polarizer was mounted in a rotating mount fitted to the front of the camera lens by means of an adapter ring.

In the case shown, the view was oblique, the illumination conditions were stable, and the sky was clear. In this case, interest was focused on the polarization of light reflected from vegetation, and from camouflage netting and standard reflectors of different albedo, both shadowed and sunlit. The degree of polarization and the other Stokes parameters were calculated using algorithms specified in references 1, and 3-8.

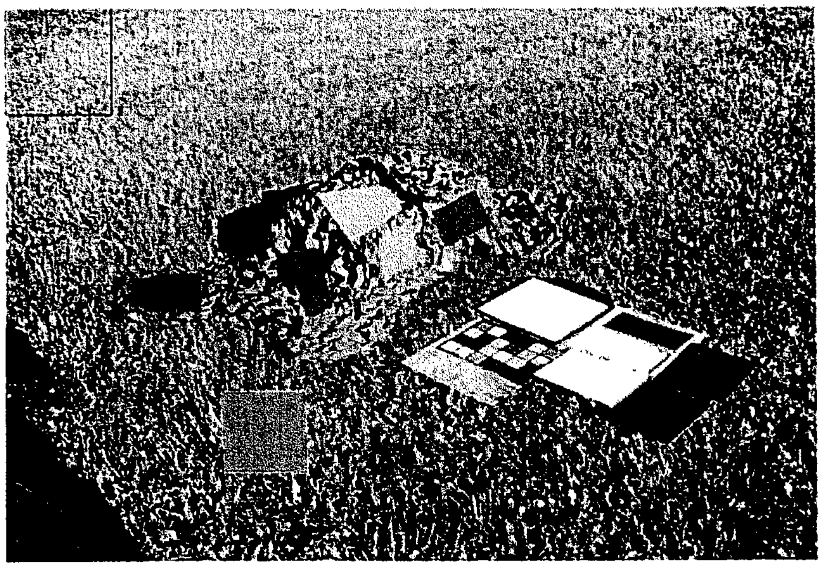

Figure 1. Standard targets, camouflage net, and shadow on a grass background. Some of the regions of interest used in the analysis are indicated.

The corresponding polarization image, calculated using the expression scaled U and V values (using an offset of 256 for the 8-bit data analyzed) to prevent error due to negative values in these images, is shown in Figure 2.

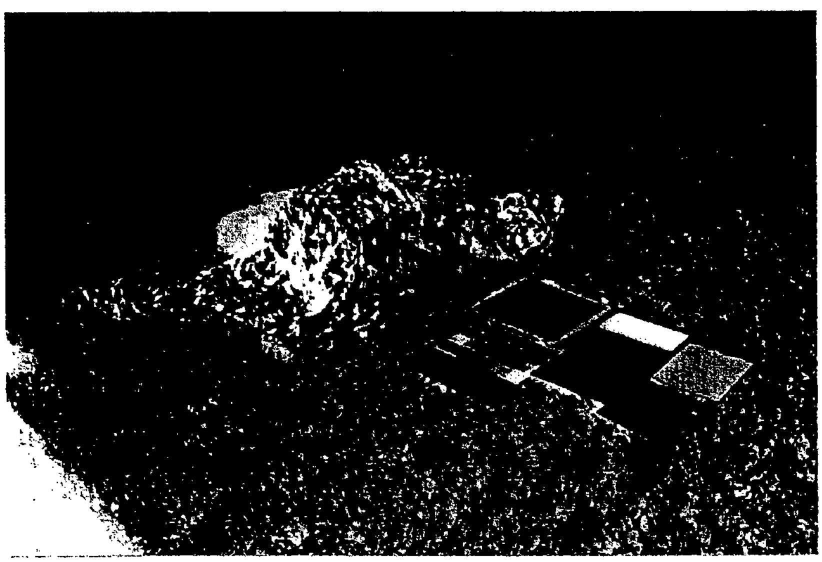

Figure 2. Polarization image calculated from the four images of the scene shown in Figure 1 and obtained with the linear polarizer incremented 45^0 about the optic axis of the camera.

An attempt was made to prepare artificial targets using camouflage paint. However, these targets appeared gray in near infrared light and were not at all like vegetation. Such efforts were generally discarded in favor of gray targets and the MacBeth color panels. Polarizers opaque to visible light, as well as HN38S, were also used during the investigation.

A considerable volume and diversity of data was collected with the DCS 460 CIR camera, as well as some data collected at different view and illumination angles. Polarizers opaque to visible light as well as HN38S were also used to support the investigation. The digital radiance values from the scene shown in Figures 1 and 2 are plotted vs. standard reflector albedo in Figure 3.

$$a1 := \text{slope}(x, y1) \quad a2 := \text{slope}(x, y2) \quad a3 := \text{slope}(x, y3)$$

$$b1 := \text{intercept}(x, y1) \quad b2 := \text{intercept}(x, y2) \quad b3 := \text{intercept}(x, y3)$$

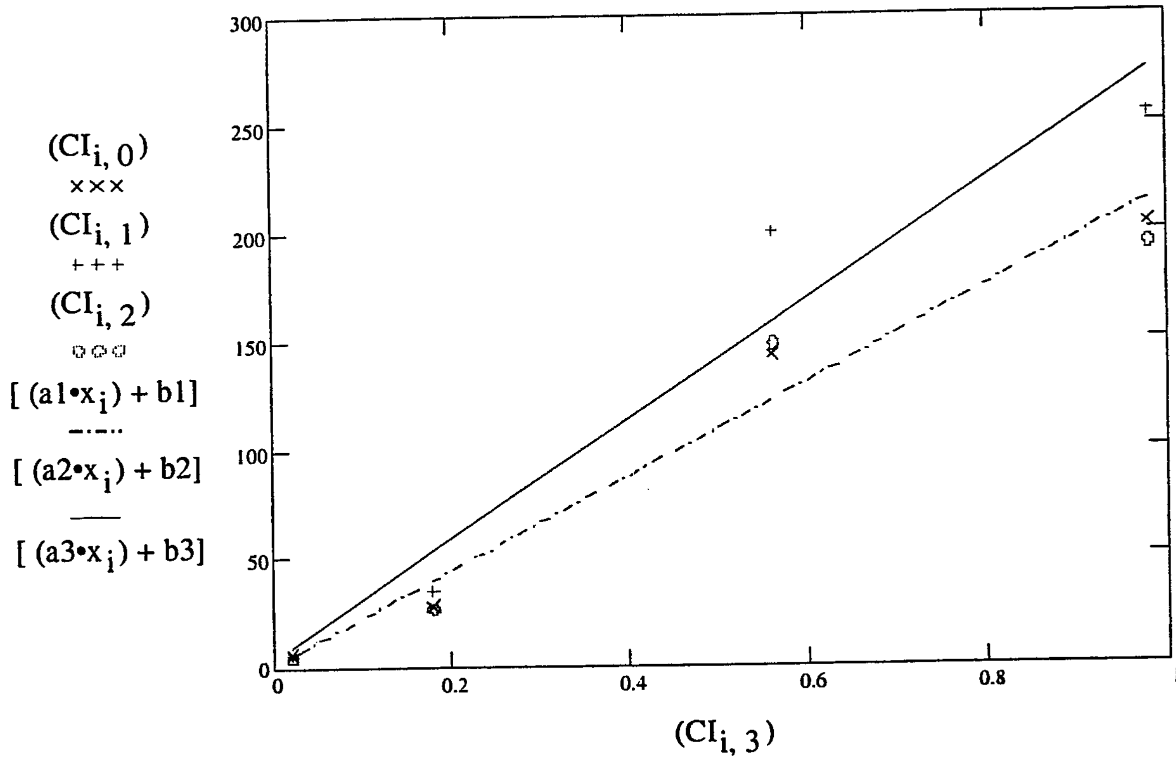

Figure 3. Radiance in the green, red and NIR bands plotted as a function of standard target albedo. The radiance from the 98% reflective Spectralon saturates the camera.

Figures 4-6 show the logarithm of the percent polarization of the reflected radiance plotted against the log of the scene radiance for the NIR, red and green bandpasses, respectively. Interestingly, the plots are linear.

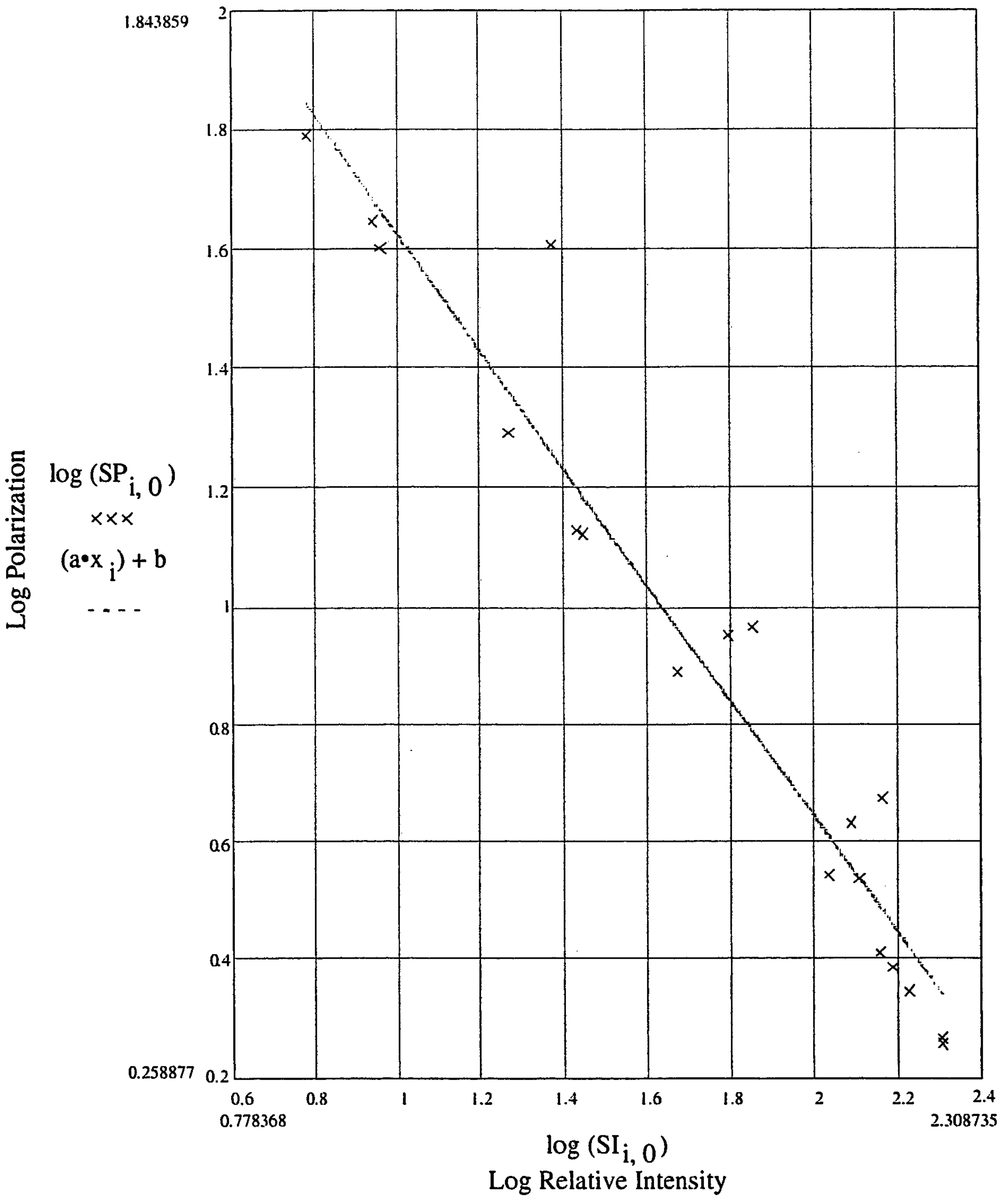

Figure 4. Log of the polarization of recorded radiance in the NIR band plotted against the log of the scene radiance for uniformly illuminated artificial gray targets shown in Figure 1.

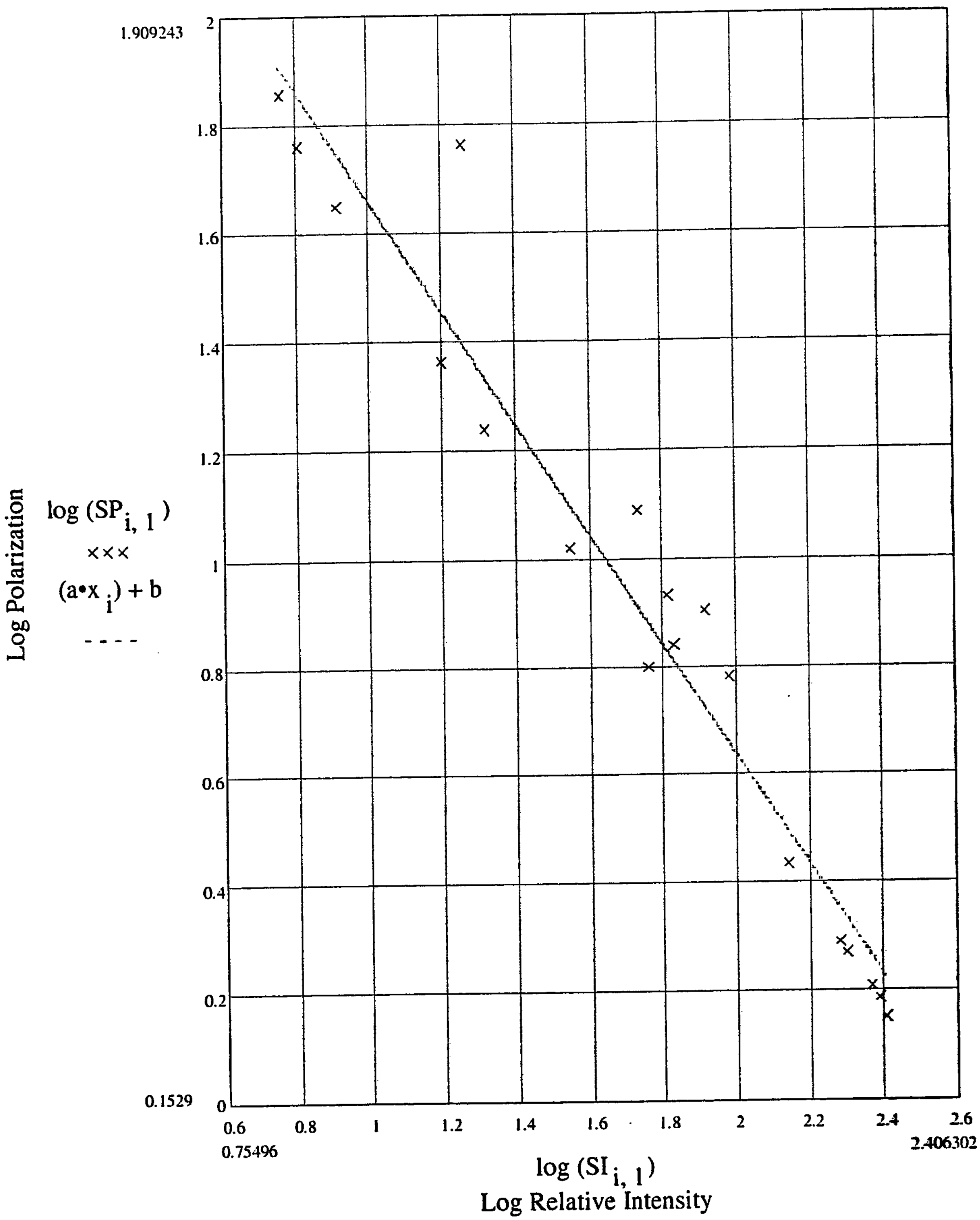

Figure 5. Log of the polarization of recorded radiance in the red band plotted against the log of the scene radiance for uniformly illuminated artificial gray targets shown in Figure 1.

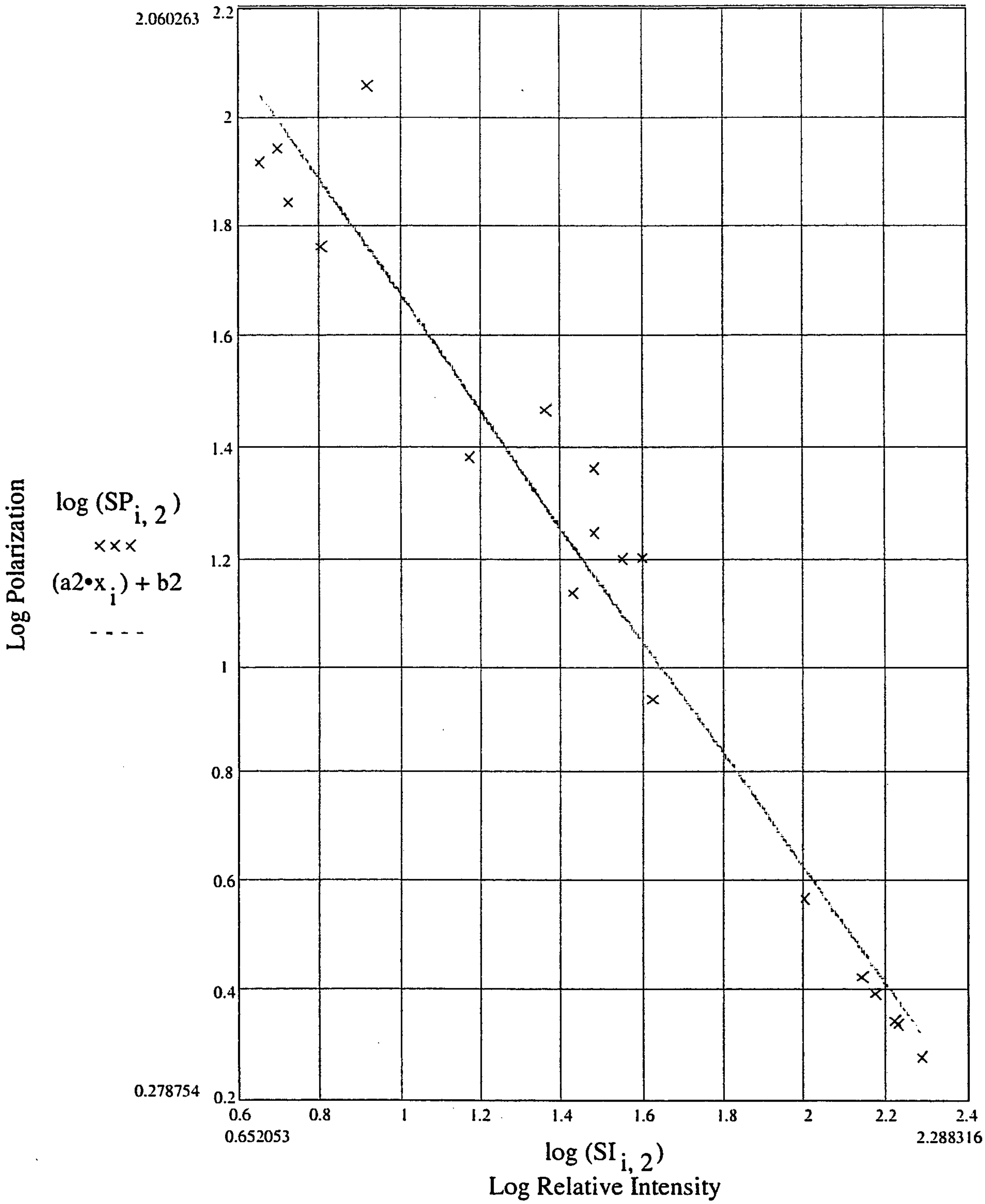

Figure 6. Log of the polarization of recorded radiance in the green band plotted against the log of the scene radiance for uniformly illuminated artificial gray targets shown in Figure 1.

In the following example, a highly shadowed area under a B52 on static display outside Rome Laboratory was imaged. It is shown in Figure 7.

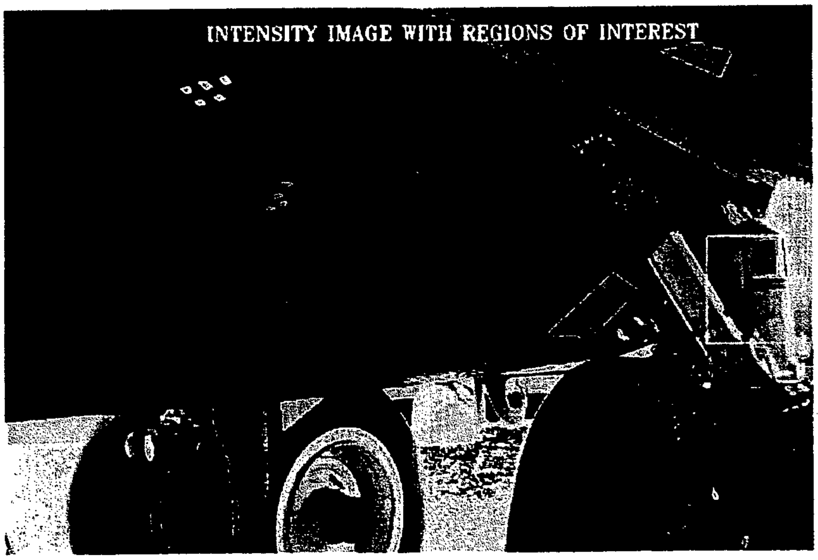

Figure 7. Intensity image of shadowed B52 on static display outside Rome Laboratory. The entire aircraft, including inside the shadowed wheel-well appears to be coated with the same paint, except the wheels and chromed shock absorbers.

The image of the degree of polarization is shown in Figure 8.

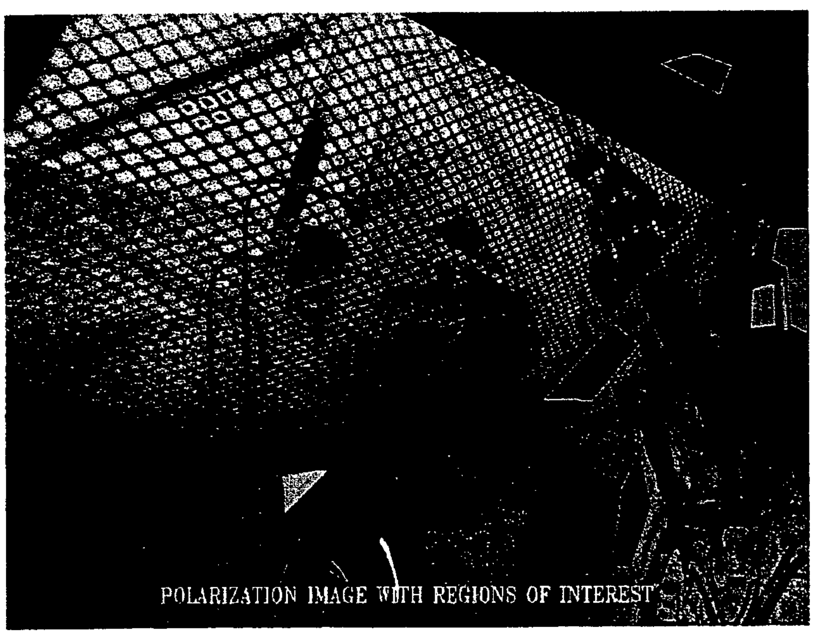

Figure 8. Degree of polarization in scene radiance recorded in Figure 7.

The degree of polarization plotted against the recorded radiance from the regions of interest selected in this scene is shown plotted in Figures 9-11 for the NIR, red and green bandpasses, respectively.

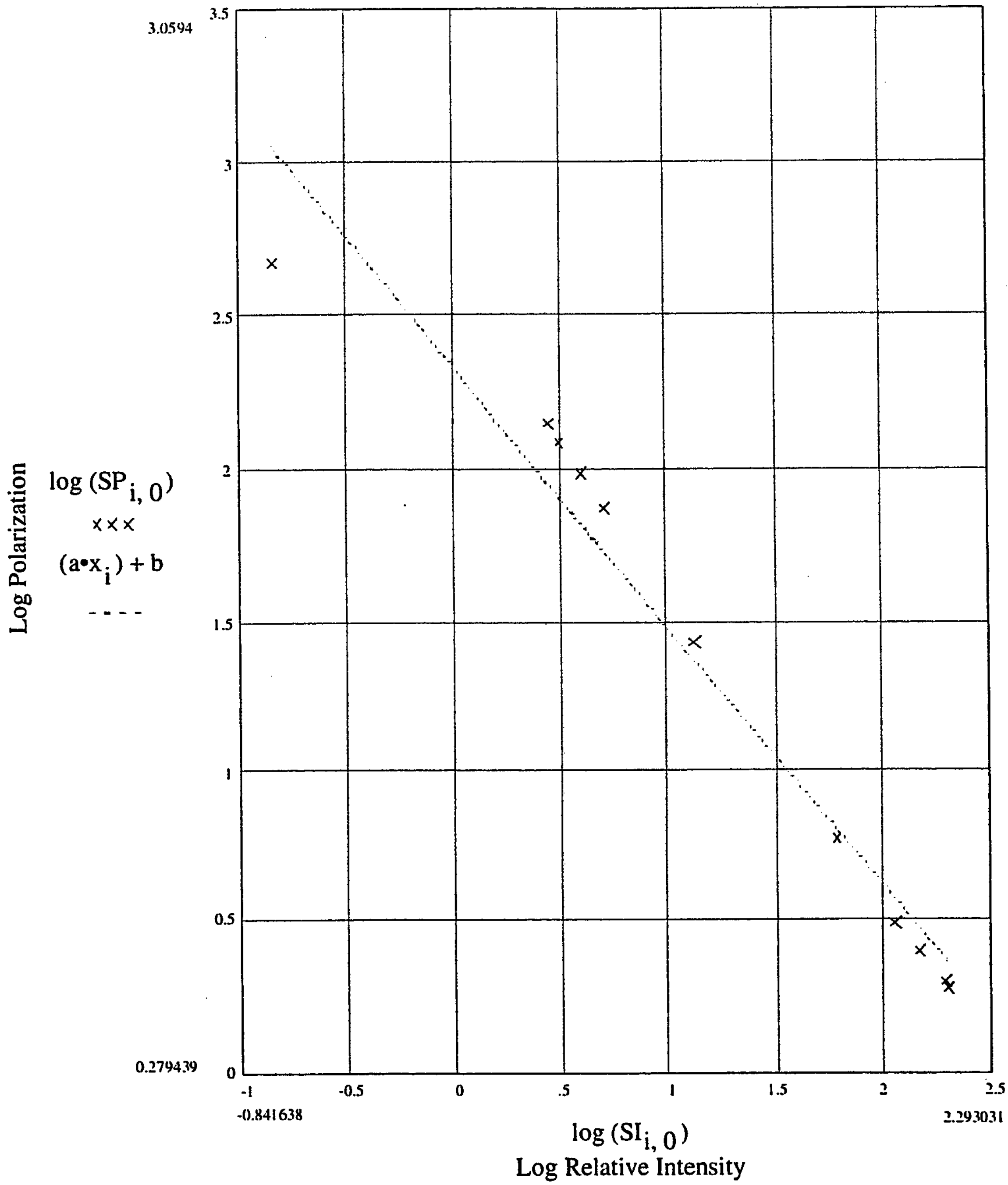

Figure 9. The degree of polarization plotted against the recorded radiance for the NIR band in the scene shown in Figure 7.

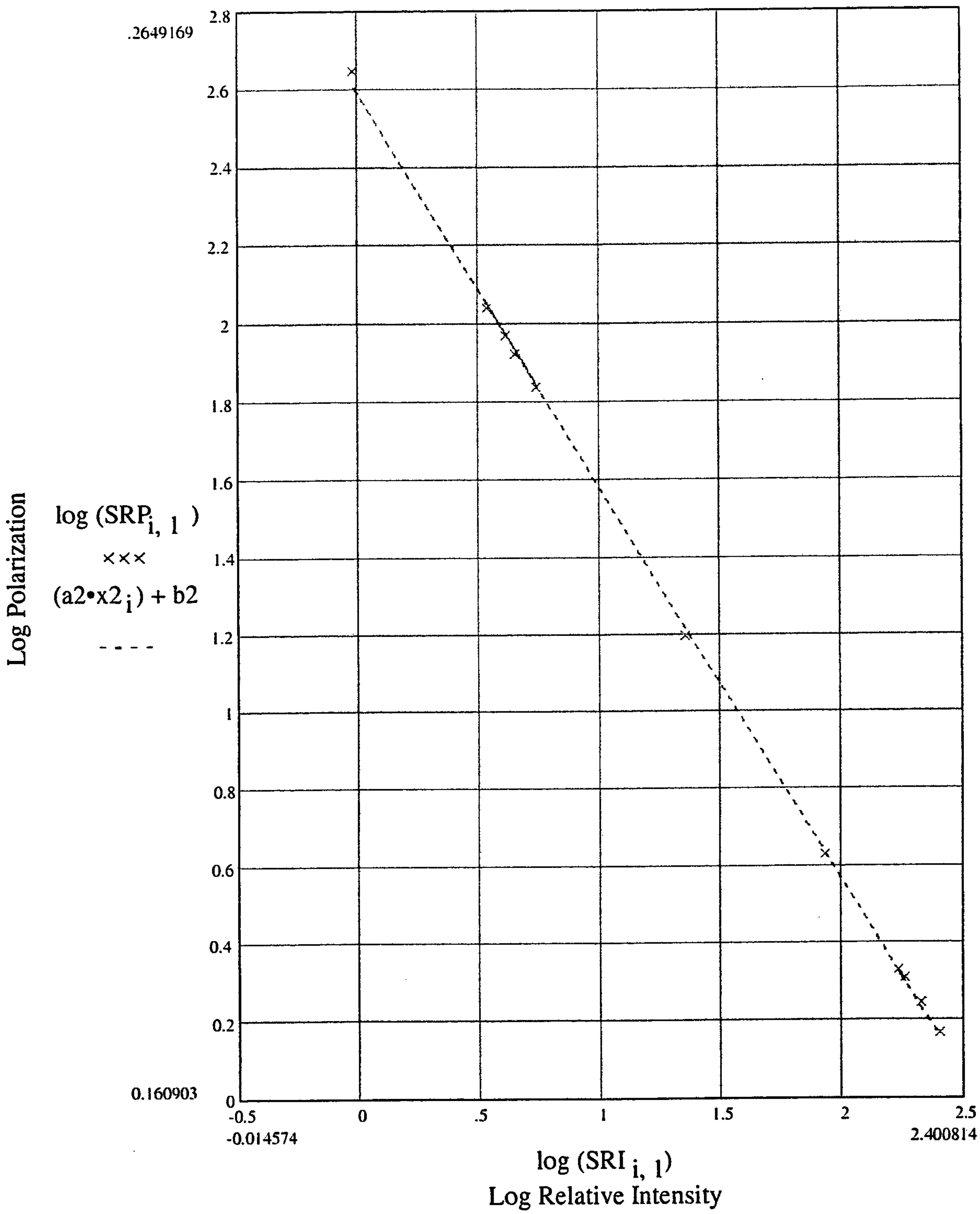

Figure 10. The degree of polarization plotted against the recorded radiance for the red band in the scene shown in Figure 7.

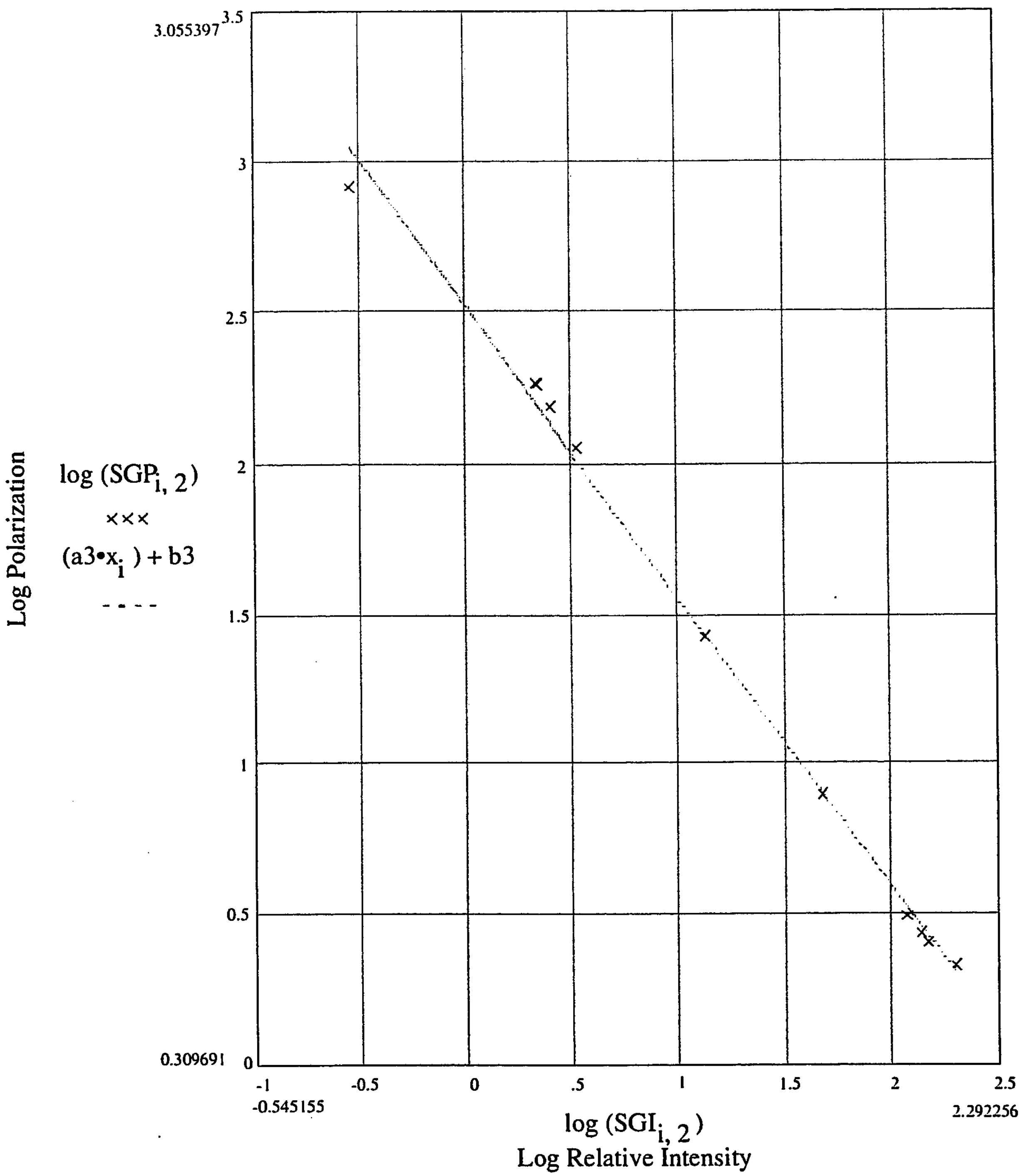

Figure 11. The degree of polarization plotted against the recorded radiance for the green band in the scene shown in Figure 7.

After pooling the data, the results for the NIR, the red, and the green bands are shown in Figures 12-14, respectively.

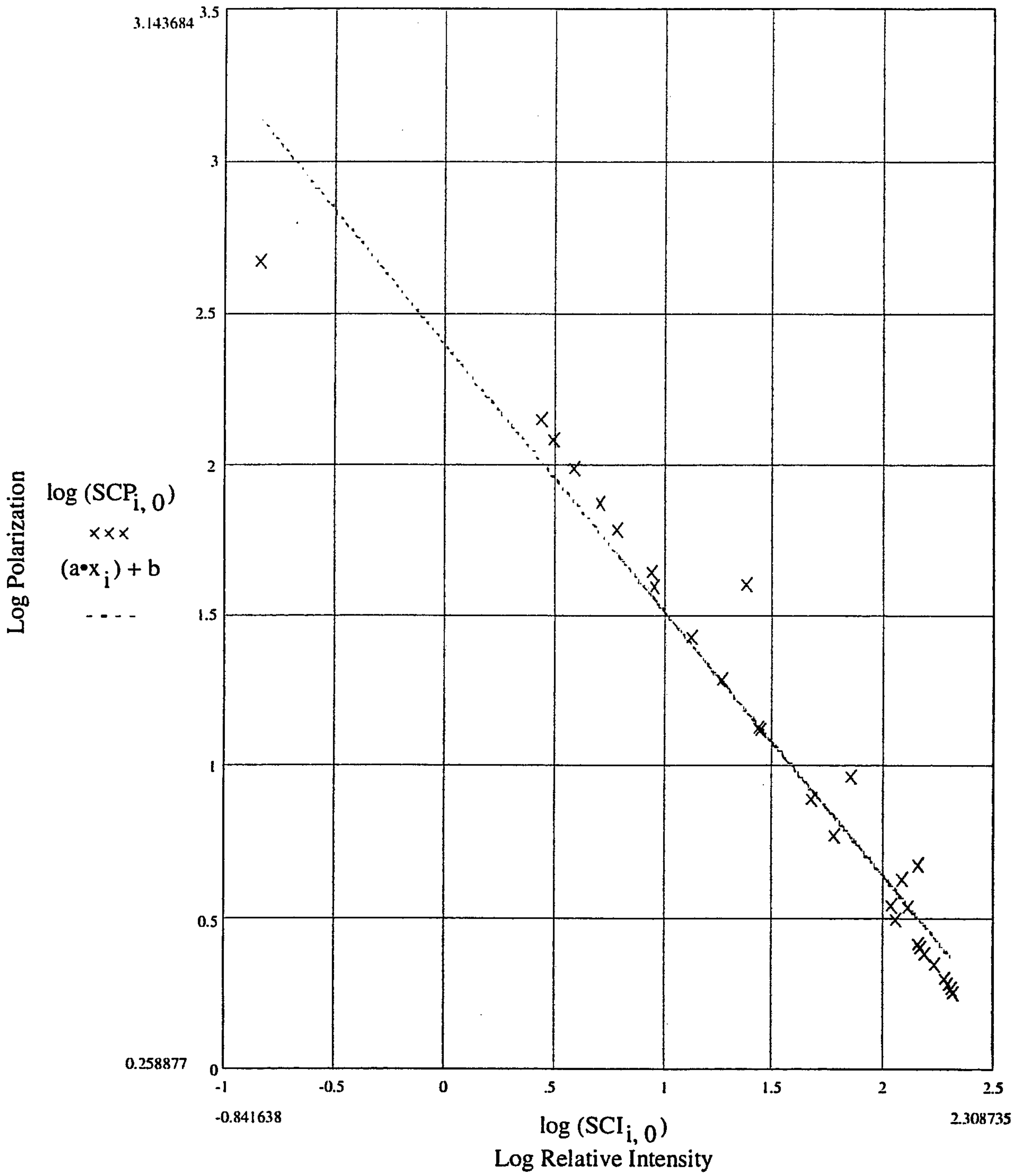

Figure 12. Pooled data in NIR band showing dependence of the degree of polarization on scene radiance.

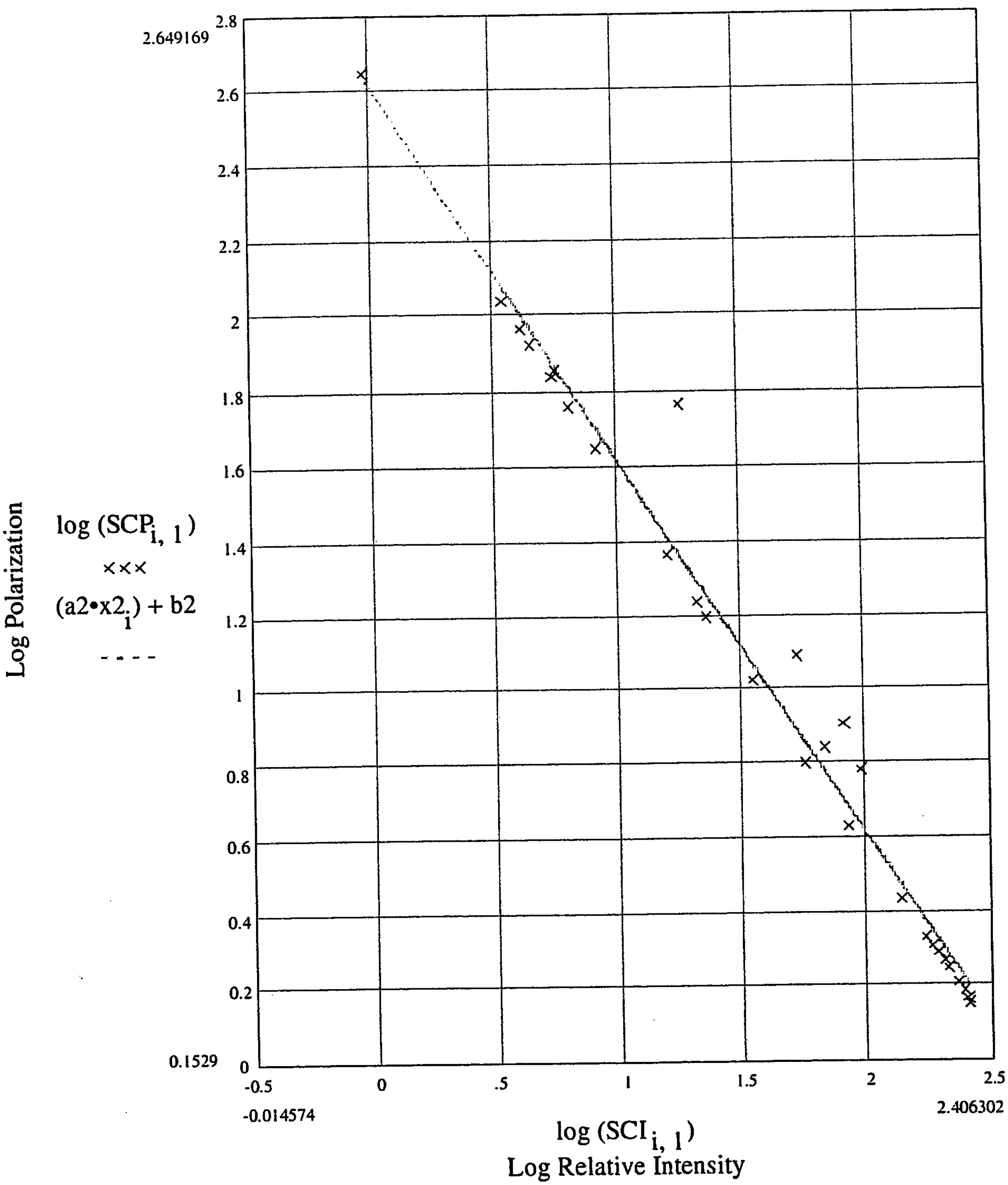

Figure 13. Pooled data in red band showing dependence of the degree of polarization on scene radiance.

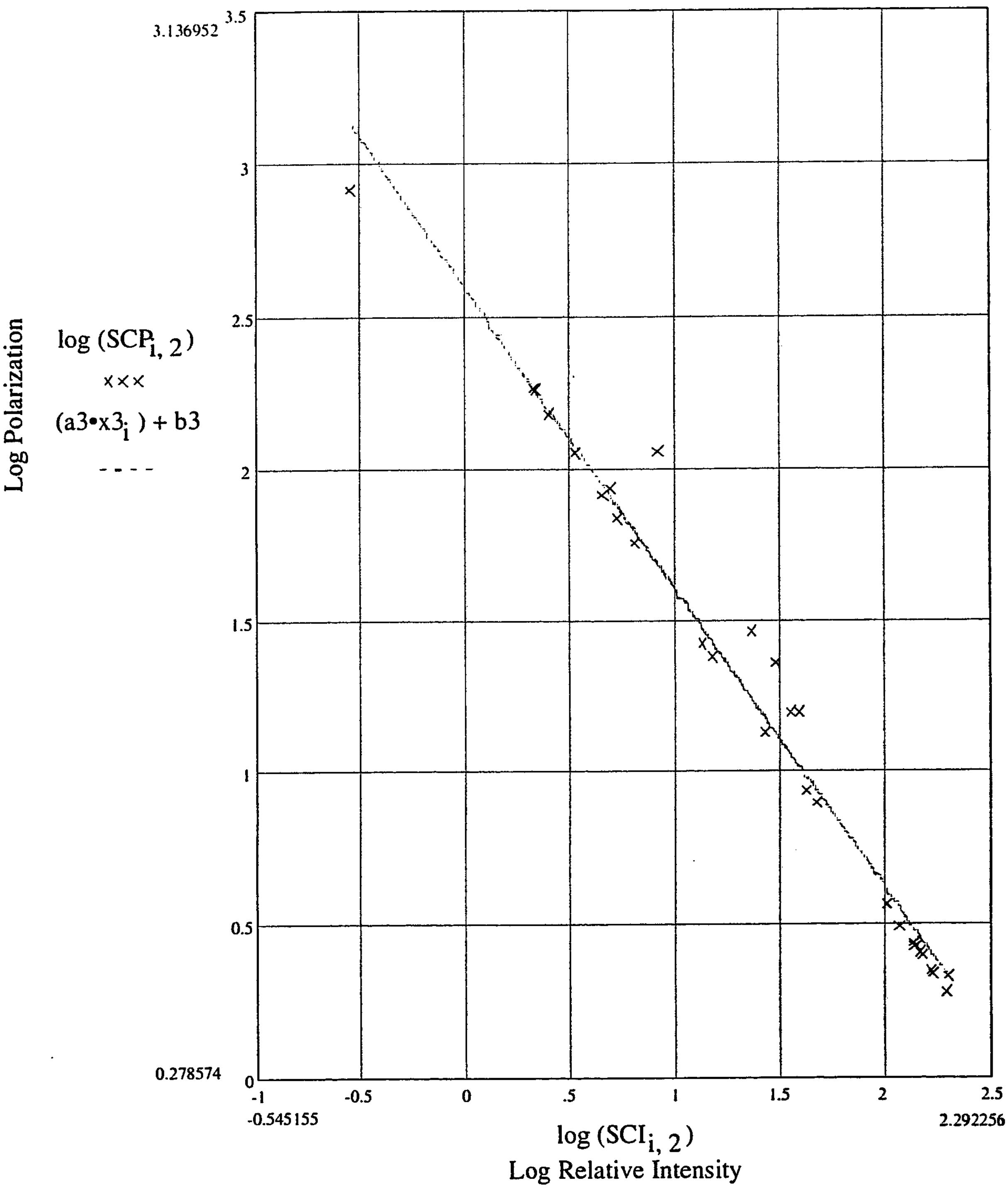

Figure 14. Pooled data in green band showing dependence of the degree of polarization on scene radiance.

The slope and intercept values for the three bandpasses for the logarithm of the degree of polarization plotted against the logarithm of scene radiance for slected image areas over the grass, camouflage net, and artificial reflectance targets shown in Figure 1 are presented in Table 1.

Table 1, Slope and Intercept for the Three Bandpasses

	near infrared band	**red band**	**green band**
slope	-0.983	-1.019	-1.055
intercept	2.609	2.678	2.733

The values for selected image areas in the shadowed B52 wheel-well shown in Figure 7 are provided in Table 2.

Table 2, B 52 Slope and Intercept Values

	near infrared band	**red band**	**green band**
slope	-0.859	-1.014	-0.968
intercept	2.337	2.596	2.528

The slope and intercept values of the best fit curves for the three bandpasses for the pooled data are shown in Table 3.

Table 3, Slope and Intercept for Best Fit Curve

	near infrared band	**red band**	**green band**
slope	-0.881	-1.005	-.987
intercept	2.402	2.624	2.599

These values are very consistent. There is strong dependence of the degree of polarization on the value of the scene radiance. Scene radiance variations are due to target type, target albedo, level of illumination, or depth of shadow. In a vegetation canopy, morphological variations and wind can control the depth and spatial variation of shadow. Also, in the bandpasses examined, there is a small bandpass-dependence.

4. CONCLUSIONS AND RECOMMENDATIONS

This investigation has shown beyond any doubt that there is a linear relationship between the log of the scene intensity and the log of the degree of polarization of the scene radiance. It was possible to cover the dynamic range of scene radiance necessary to establish this relationship for two reasons. First, the Kodak DCS 460 is a stable linear imaging device. Second, a great deal of careful work has been accomplished that has enabled reliable radiometric calibration of this device.

There is no question that for some scenes, and for some of the regions of interest selected within these scenes, there is more surface scattering and more atmospheric scattering than in other cases. The level to which atmospheric and surface scattering affect the relationship between the degree of polarization and scene radiance level within a given band is as yet unclear. Also, situations where radiance comes from radiant sources within the scene have yet to be examined.

A wealth of information exists in the images collected during 1987 and 1988. Further analysis is required in order to study, for example, the dependence of the level of polarization on color. Many images have been obtained at several view and illumination geometries of the Spectralon and Kodak gray targets. Included in the same images are color patches of known hue and saturation (the MacBeth Color Checker card). These patches are reasonably Lambertian in that there is no evident specularity at various view angles.

It is recommended that investigation of the hue- and saturation-dependence of polarization be performed. This can be performed by plotting polarization vs. hue and saturation for a given scene (all targets horizontal and evenly illuminated under clear sky conditions) using a modified CIE diagram and a modified Munsell 3-D plot. This could prove to be a further discriminator of man-made targets from vegetation. The investigation would determine whether the degree of polarization depends on hue and saturation, as well as on intensity, and to determine if this might be used to distinguish camouflage from vegetation. This can be achieved with further study of the data collected this past summer.

While this study relates to three quite broad bandpasses, the dependencies found in the analysis of this simple data will lead to studies relating to multispectral and hyperspectral data acquisition and analysis. The polarization characteristics in narrow bandpasses near the red edge, near the blue edge, and near water absorption bands will more clearly distinguish vegetation from non-vegetation, and help identify vegetation type, as well as vegetation stress (chemical and mechanical). For these reasons, further analysis of the data collected is recommended.

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